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RESEARCH ARTICLE

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Comparative osteology and osteometry of the coracoideum, humerus, and femur of the green turtle (*Chelonia mydas*) and the loggerhead turtle (*Caretta caretta*)

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Abstract

Fragmented skeletal remains of marine turtles occur frequently in archaeological and natural deposits on tropical and subtropical coasts. Identifying these remains to species based on their differential osteomorphology is vital to address questions pertaining to the historical ecology, archaeology, and conservation of marine turtles globally. Although the species-specific features of extant marine turtle skulls and carapax are relatively well known, the comparative osteomorphology and osteometry of postcranial endoskeletons in closely related species of marine turtles remains unstudied. In this paper, we provide verbal descriptions, line drawings, and photographs of diagnostic morphological criteria for the coracoideum, the humerus, and the femur of two closely related species of Cheloniidae: *Chelonia mydas* (green turtle) and *Caretta caretta* (loggerhead), based on observations on modern skeletons. We also present osteometric indices of the humerus and the femur that can be used to distinguish between both species. We comment on the applicability of these criteria on archaeological marine turtle assemblages from the Mediterranean.

KEYWORDS

Caretta caretta (loggerhead), *Chelonia mydas* (green turtle), comparative osteology, osteometry, postcranial skeleton, taxonomic identification

1 | INTRODUCTION

Marine turtles inhabit all subtropical oceans in the world and are keystone species of marine ecosystems (Jackson et al., 2001). Marine and coastal biologists work with live marine turtles, as well as their washed-up body parts (e.g., Bjorndal, Bolten, & Lagueux, 1994; Epperly et al., 1996). Zooarchaeologists are confronted with marine turtle remains from a wide variety of temporal and geographic contexts (Frazier, 2003). Such remains potentially provide invaluable hard data that can serve to identify the "shifting baselines" (sensu Pauly, 1995) of marine turtle populations (Çakirlar, Koolstra & Ikram, in prep.).

Identification to species is a prerequisite to realize the potential of archaeological and recent turtle parts. Although recent and/or intact marine turtle parts can be readily identified based on a number of distinguishing features on their soft tissue and skull (cranium and mandibula), identifying culturally modified and eroded postcranial endoskeletal fragments to species remains a challenge.

The aim of this study is to present an osteomorphological and osteometric guide for zooarchaeologists and biologists who work with the remains of closely related extant marine turtles. We established osteomorphological criteria that distinguish the green turtle (*Chelonia mydas*) and the loggerhead (*Caretta caretta*) based on the coracoideum, humerus, and femur. In addition, we also present osteometric criteria of the humerus and the femur to distinguish between both species. We present the criteria verbally and visually in an accessible way that can be used by zooarchaeologists and biologists. We discuss our results in comparison with previously published osteomorphological observations on marine turtles. We then explain how we used the criteria to estimate relative abundance of species at Kinet Höyük, a Bronze Age to Medieval Period site on the Mediterranean coast of southern Turkey, and Tell Fadous-Kfarabida, a Late Chalcolithic to Middle Bronze Age mound on the Lebanese coast.

2 | BACKGROUND AND STATE OF RESEARCH

There are seven extant marine turtle species classified in two families: Cheloniidae and Dermochelyidae. The Cheloniidae comprise six of the seven living species: the green turtle (*Chelonia mydas*), the loggerhead (*Caretta caretta*), the hawksbill (*Eretmochelys imbricata*), Kemp's ridley (*Lepidochelys kempi*), the olive ridley (*Lepidochelys olivacea*), and the flatback turtle (*Natator depressus*). The Dermochelyidae include one living species, the leatherback (*Dermochelys coriacea*). Extant marine turtles can be identified to species based on several external characteristics, including the scales on the head, the number of claws on the feet, the pattern and the number of scutes of the carapax and plastron, and the form of the limbs and the body (Kamezaki, 2003, pp. 28–33; Parham & Fastovsky, 1997, pp. 550–551; Pritchard & Mortimer, 1999; Wyneken, 2001, pp. 1–8; 2003, p. 40).

Publications on osteological differences, however, are limited and so far primarily focused on the morphology of the cranium, the mandibula, the carapax, and the plastron, the latter providing accurate identifications only for adult individuals (Carr, 1952, pp. 341–410; Gaffney, 1979, pp. 285–293; Kamezaki, 2003, pp. 33–41; Parham & Fastovsky, 1997, pp. 551–552; Pritchard, 1969, pp. 91–113; 1989, p. 161; Ruckdeschel & Shoop, 2006, pp. 109–124; Wyneken, 2001, pp. 8–25, 51; 2003, pp. 49–52). Osteological differences in other postcranial endoskeletal elements have also been discussed, but mainly comparing higher taxa (e.g., Cheloniidae vs. Dermochelyidae), tackling differences among recent and fossil tortoises, freshwater and marine turtles. The main purpose of these discussions is to explain phylogenetic relationships, functional morphology, and environmental adaptation (Depecker, Berge, Penin, & Renous, 2006; Depecker, Renous, Penin, & Berge, 2006; Hay, 1908, pp. 15–16; Hirayama, 1992, 1994; Nakajima, Hirayama, & Endo, 2014; Parham & Fastovsky, 1997, pp. 550–551; Völker, 1913, pp. 450, 453–454, 465–466, 505; Wieland, 1900; Williams, 1950).

Published morphological distinguishing criteria for marine turtle limb bones are rare. Moreover, they bear limitations for understanding differences among closely related species within a family. Völker (1913, p. 454) describes the extraordinary form of the tuberositas deltoidea (respectively, processus lateralis) on the humerus of *Dermochelys coriacea*, which has two separated attachment areas, one for the musculus deltoidea and one for the supracoracoid, and explains that in all other marine turtles (i.e., Cheloniidae), these areas are united to one tuberositas. Hirayama (1992, p. 18) points out this difference between *Dermochelys coriacea* and Cheloniidae as well.[1] Depecker, Berge, et al. (2006, p. 42) use geometric morphometrics to tackle phylogeny based on osteomorphology and concludes that the morphology of the shoulder girdle (scapula and coracoideum) of Cheloniidae and Dermochelyidae show a homogeneity, except for *Caretta caretta*, which displays a morphology similar to freshwater turtles. Nakajima et al. (2014, p. 725, figure 6) note differences in the thickness of the substantia compacta of humeri of *Eretmochelys imbricata*, *Dermochelys coriacea*, *Caretta caretta*, and *Chelonia mydas*. Wyneken (2001, p. 55, figure 105) compares the inner structure of the Substantia spongiosa of *Dermochelys coriacea* and *Caretta caretta* limb bones, as a distinguishing aspect between these species.

Parham and Fastovsky (1997) discuss differences in the morphology of scapula, coracoideum, humerus, femur, and tibia of *Natator* and 12 other Cheloniidae genera (including eight extinct genera). They observe that in *Natator* the trochanter major and minor of the femur are separated by a notch, whereas in *Caretta*, *Chelonia*, *Eretmochelys*, and *Lepidochelys* trochanter major and minor are connected by a ridge. Parham and Fastovsky (1997, pp. 550–551) also point out differences in the tibial pit for the musculus pubotibialis and the musculus flexor tibialis internus. In *Natator* the tibial pit is present, whereas in *Caretta*, *Chelonia*, *Eretmochelys*, and *Lepidochelys*, it is absent. The descriptions of Parham and Fastovsky (1997) come closest to what researchers dealing with extant marine turtle limb bones might actually need to distinguish among Holocene remains with cryptic origins. The published osteomorphological criteria on limb bones of marine turtles we found so far are summarized in Table 1.

3 | MATERIAL AND METHODS

We examined marine turtle skeletons from eight reference collections in five countries for osteomorphological landmarks on endoskeletons and took osteometric measurements. Because our identification question evolved out of an archaeozoological question pertaining to endoskeletal remains from Eastern Mediterranean sites, our quest aimed at comparative skeletons of the species inhabiting the Mediterranean Sea, which are *Chelonia mydas*, *Caretta caretta*, *Eretmochelys imbricata*, and *Dermochelys coriacea*.

Nowadays, *Dermochelys coriacea* lives primarily in the Atlantic Ocean and only occasionally visits the Mediterranean. At present, there is no evidence of nesting sites in the Mediterranean (Casale et al,. 2003; Casale et al., 2010, p. 4). Moreover, adult *Dermochelys coriacea* are much larger than Cheloniidae, and being in a different family, they are morphologically

[1]According to Hirayama (1992, p. 18) in *Dermochelys coriacea* is "The lateral process nearly straight and elongate in anteroposterior direction on the ventral surface of humeral shaft, with strong anterior projection inserted by the deltoid muscle," whereas in Cheloniidae is "The shoulder of caput humerus completely absent. The lateral process more distally locating, separated from the caput humerus. The lateral process triangular or V shaped, with strong ridge inserted by the deltoid muscle. Humeral shaft expanded and flattened, with enlarged and deep scar for the M. latssimus dorsi, M. teres major, and M. coracobrachialis brevis."

TABLE 1 Overview of publications containing morphological data of marine turtle limb bones

Reference	Species and elements described or illustrated					
	Caretta caretta	*Chelonia mydas*	*Dermochelys coriacea*	*Eretmochelys imbricata*	*Lepidochelys* (not specified whether this concerns *Lepidochelys olivacea* or *kempi* or both)	*Natator depressus*
Depecker, Renous, et al., 2006, 516, figure 2	Principal component analysis (PCA) and descriptions of humerus	Principal component analysis (PCA) and descriptions of humerus	Principal component analysis (PCA) and descriptions of humerus	Principal component analysis (PCA) and descriptions of humerus		
Depecker, Berge, et al., 2006, 42, figure 3	Principal component analysis (PCA) and descriptions of scapula and coracoideum	Principal component analysis (PCA) and descriptions of scapula and coracoideum	Principal component analysis (PCA) and descriptions of scapula and coracoideum	Principal component analysis (PCA) and descriptions of scapula and coracoideum		
Hay, 1908, 16			Descriptions of scapula, coracoideum, humerus, radius, and ulna			
Hirayama, 1992, 18, 23, figure 3	Drawings and description of humerus		Drawings and description of humerus			
Hirayama, 1994, 274–276, 281–282, figure 6	Drawing and description of humerus		Description of humerus			
Nakajima et al., 2014, 725, figure 6	3D translucent image, virtual cross section and description of humerus	Description of humerus	3D translucent image, virtual cross section and description of humerus	3D translucent image, virtual cross-section and description of humerus		
Parham & Fastovsky, 1997, 550–551, table 1, Criteria 11, 13, 15, 18, 19	Descriptions of scapula, coracoideum, humerus, femur, and tibia	Descriptions of scapula, coracoideum, humerus, femur, and tibia		Descriptions of scapula, coracoideum, humerus, femur, and tibia	Descriptions of scapula, coracoideum, humerus, femur, and tibia	Descriptions of scapula, coracoideum, humerus, femur, and tibia
Rhodin, Ogden, & Conlogue, 1980, figure 1			Drawing of a longitudinal section of humerus			
Rhodin, 1985, 760, 763, figures 6 and 9			Photos of longitudinal cross section of humerus			
Völker, 1913			Drawings and descriptions of coracoideum, humerus, radius, and femur			
Wieland, 1900, figure 7, 11, 21–23	Drawings and description of humerus	Drawing and description of humerus	Drawing and description of humerus			
Wyneken, 2001, 53–58			Photos and drawings of humerus, radius, ulna, femur, tibia, and fibula			

visibly distinct from other sea turtles. *Eretmochelys imbricata* is extremely rare in the Mediterranean today (Clarke et al,. 2000, p. 364; Coll et al., 2010, p. 8). For the purpose of this study, we assume that it was also rare in the Mediterranean during the Holocene. We therefore focused our comparative study mainly on the differences between *Chelonia mydas* and *Caretta caretta*. Nevertheless, we occasionally refer to *Dermochelys coriacea* and *Eretmochelys imbricata* if obvious differences in morphology were observed during our examination.

We examined in total 26 specimens of *Chelonia mydas* (*n* = 16), *Caretta caretta* (*n* = 8), *Eretmochelys imbricata* (*n* = 1), and *Dermochelys coriacea* (*n* = 1; Table 2), most of them being complete or nearly complete skeletons. One of us (C. Ç.) made exploratory observations at the archaeozoological and zoological collections of Tübingen University (*n* = 3) and at the Smithsonian Institution's National Museum of Natural History Collections housed at the Museum Support Center in Maryland (*n* = 9) in 2008–2010. This initial phase of research was followed by in-depth work at the skeletal collections of the University Museum of the University of Groningen (*n* = 1) and the Royal Belgian Institute of Natural Sciences Brussels (RBINS; *n* = 6) in 2017 by all of us, where the criteria presented in this paper were developed. In 2018, F. J. K. and H. C. K. visited the Royal Museum of Natural History Leiden (RMNH/Naturalis; *n* = 3), H. C. K. visited the Übersee Museum Bremen (UMB; *n* = 2), and C. Ç. visited the Department of Veterinary Anatomy at Aydın Adnan Menderes University (*n* = 2), where the criteria were checked. The species identification given by the museum labels was checked by re-identifying crania and mandibulae using criteria published by Wyneken (2001). All collection data of the specimens used in this study are summarized in Table 2.

We defined six osteomorphological criteria on three postcranial skeletal elements: the coracoideum, the humerus, and the femur. All criteria are illustrated in Figures 2, 3, 5, 6 and 7 with their respective description. Photographs depicting all criteria are presented in Figures S1 to S5 in the supplementary information.

Literature research showed that no commonly accepted nomenclature for turtle skeletal elements and for the description of directionality exists. We try to overcome possible confusion by systematically following the anatomical terms of the Nomina Anatomica Veterinaria (Gasse et al., 2012) and corresponding terminology for the coracoideum from Nickel et al. (2004, pp. 97–98). For the orientation of the elements, Wyneken (2001, p. 1) has been applied.

We tried to develop our comparative osteomorphological method in concurrence with the features we observed in the fragmented and eroded postcranial elements from the archaeological assemblages of Kinet Höyük (Turkey) and Tell Fadous-Kfarabida (Lebanon; Figure 1). We focused on these endoskeletal elements because of their frequent occurrence (in addition to carapax and plastron fragments) as far as we can tell from the published archaeological materials (see Frazier, 2003, and Çakirlar, Koolstra & Ikram, in prep., for an overview of the published archaeozoological materials) and the assemblages we have studied (Çakirlar, Koolstra & Ikram, in prep.). For example, at Kinet Höyük, 46% of the limb bones recovered represent the pectoral girdle including the coracoideum, 22% represent the humerus, and 13% represent the femur (*n* = 153; Çakirlar, Koolstra & Ikram, in prep.). At Tell Fadous-Kfarabida, 30% of the limb bones belong to humeri (*n* = 66; Çakirlar, Koolstra & Ikram, in prep.). At Qala'at al Bahrain on the Red Sea coast, the humerus makes up more than half of the postcranial specimens recovered (Uerpmann & Uerpmann, 1994, p. 418). At Sidon, a coastal site in Lebanon, from which the turtle assemblage is not fully published, Vila (2006, p. 315) found only femora and humeri bones worth mentioning specifically in her summary of the faunal remains. However, most publications do not discuss the skeletal element distribution of sea turtle remains from archaeological contexts.

We also established osteometric indices to examine the relation between the greatest length (GL) and the breadth of the shaft (BSH) for humeri and femora, following measurements suggested in Zug, Balazs, Wetherall, Parker, and Murakawa (2002) and creating our own measurements inspired by von den Driesch (1976). All osteometric data are summarized in Table S1 in the supplementary information.

The exact age of the specimens we examined was not provided in the collection data. Judged by the size and surface structure of the bone most of the specimens examined at RBINS, RMNH and UMB were juvenile, except for one adult *Chelonia mydas* (UMB 1). When possible we measured the minimum straight-line carapace length (= SCLmin) and/or minimum curved carapace length (= CCLmin). These are standard measurements in turtle biology that are used as rough indicators for relative age at death (Wyneken, 2001, pp. 28–29). Size at juvenile, immature, and adult age shows variability among sea turtle populations. For example, beach surveys of several nesting seasons show that the CCLmin for *Caretta caretta* from the Mediterranean Sea (Cyprus, Alagadi Beach) is 63.0 cm (Broderick et al,. 2003), whereas the CCLmin for *Caretta caretta* from the South Atlantic Ocean (Brazil, Espírito Santo) is 83.0 cm (Baptistotte, Thomé, & Bjorndal, 2003). The CCLmin for *Chelonia mydas* from the Mediterranean Sea (Cyprus, Alagadi beach) is 77.0 cm (Broderick et al., 2003), while the CCLmin for *Caretta mydas* from the North Atlantic Ocean is 92.0 cm (Frazer & Ehrhart, 1985). The *Caretta caretta* specimens we studied range between 29.4 cm SCLmin (= 33.4 cm CCLmin) and 59.0 cm SCLmin (= 63.0 cm CCLmin) and the *Chelonia mydas* specimens between 31.5 cm SCLmin (= 35.5 cm CCLmin) and 65.0 cm SCLmin (= 69.0 cm CCLmin), indicating that, based on measurements, most of them are juvenile specimens, as the data from the surveys are based on measurements from sexual mature (female) turtles that come ashore.

We do not consider the possible presence of juvenile individuals in the sample we studied as a serious limitation. As marine turtle bones grow incrementally in skeletal laminae secreted at the outer edge of the bone, in contrast to mammalian bone that typically grows from an ossification centre later forming clear epiphyses, ontogenetic remodelling in structure and shape of skeletal tissue are limited in marine turtles, causing proportional allometry throughout life (Bjorndal, Bolten, & Martines, 2000; Bjorndal et al., 2013; Zug et al., 2002). In other words, the morphology of endoskeletal elements in immature and mature individuals is largely similar. To test the applicability of our diagnostic criteria on individuals of adult age, we asked Ren Hirayama to check our criteria on his reference collection at Waseda University Tokyo. He checked our results on two adult *Caretta caretta* (RH 229, RH 786) and one *Chelonia mydas* skeleton (RH 800; right humerus only) and confirmed the validity of our observations.

TABLE 2 Collection data of specimens from modern skeletal reference collections used in this study

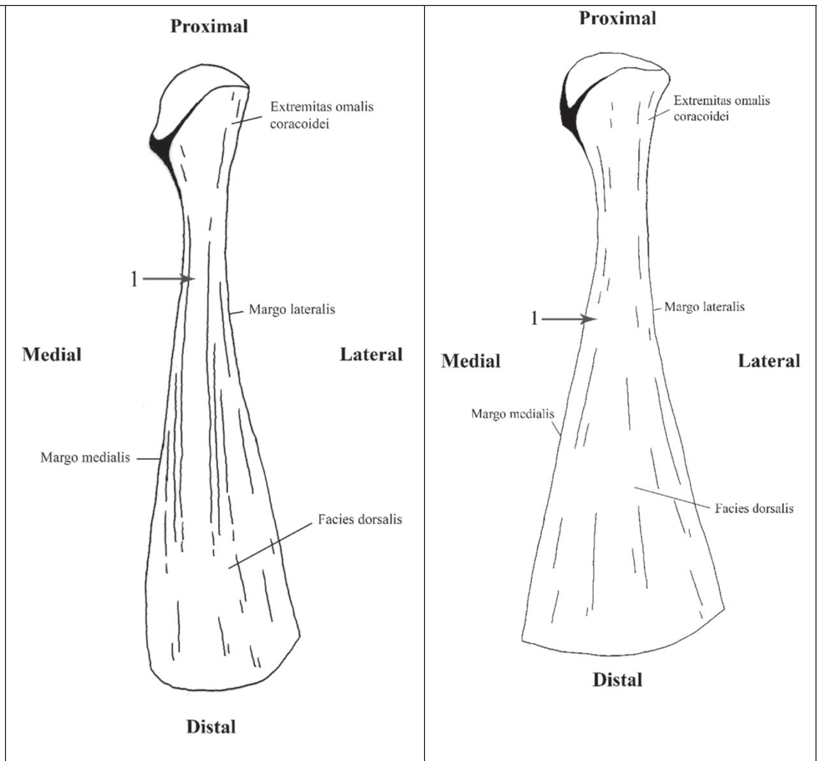
	Specimen number	Species	Preservation status	Sex	Collection date	Geographical origin	Visited by
Royal Belgian Institute of Natural Sciences, Science Museum, Brussels	RBINS 4.534	*Chelonia mydas*	Complete, partially mounted limbs, skull, carapax	—	21-12-1949	—	C. Ç., H. C. K., F. J. K.
	RBINS 13.909	*Chelonia mydas*	Complete, partially mounted limbs, skull, carapax	—	01-01-1948	Mediterranean	
	RBINS 13.910	*Chelonia mydas*	Complete, partially mounted limbs, skull, carapax	F?	August 1960	Zoo Antwerpen, BE	
	RBINS 218.S	*Caretta caretta*	Complete, partially mounted limbs, skull, carapax	—	10-05-1872	Zoo Brussels, BE	
	RBINS 216.S	*Eretmochelys imbricata*	Complete, partially mounted limbs, skull, carapax	—	—	—	
	RBINS 230s	*Dermochelys coriacea*	—	—	20-12-2000	Mariakerke, BE	
Royal Museum of Natural History Leiden (Naturalis)	RMNH 35431	*Caretta caretta*	Almost complete, some limb bones missing, some carapax fragments missing	—	05-08-1998	Walcheren, NL	H. C. K., F. J. K.
	RMNH RENA 40601	*Caretta caretta*	Almost complete, carapax missing	—	—	—	
	RMNH RENA 48303	*Caretta caretta*	Some limb bones present, carapax missing	—	09-08-2015	Camperduin, NL	
Übersee Museum Bremen	UMB 1*	*Chelonia mydas*	Complete	—	—	—	H. C. K.
	UMB 2*	*Chelonia mydas*	Complete, partially mounted limbs, skull, carapax	—	—	—	
Tübingen University, Zoologische Sammlung	4191	*Caretta caretta*	Complete, mounted	—	—	—	C. Ç.
Tübingen University, Archaeozoological Reference Collection	RCL15	*Caretta caretta*	Almost complete, partial limbs, skull, carapax	—	—	United Arab Emirates	
	RCL16	*Chelonia mydas*	Complete	—	—	United Arab Emirates	
University Museum, Groningen	Z-0006	*Chelonia mydas*	Complete, mounted	—	—	—	C. Ç., F. J. K.
Aydın Adnan Menderes University, Department of Veterinary Anatomy	ADU 001	*Caretta caretta*	Complete	—	—	—	C. Ç.
	ADU 002	*Caretta caretta*	Complete, mounted	—	—	—	
Smithsonian Institution, National Museum of Natural History, Museum Support Center, Suitland, Maryland	SI NMNH 313721	*Chelonia mydas*	—	—	27-12-1989	Florida, USA	C. Ç.
	SI NMNH 313722	*Chelonia mydas*	—	—	27-12-1989	Florida, USA	
	SI NMNH 313713	*Chelonia mydas*	—	—	26-12-1989	Florida, USA	
	SI NMNH 313718	*Chelonia mydas*	—	—	26-12-1989	Florida, USA	
	SI NMNH 313723	*Chelonia mydas*	—	—	27-12-1989	Florida, USA	
	SI NMNH 313724	*Chelonia mydas*	—	—	27-12-1989	Florida, USA	
	SI NMNH 313717	*Chelonia mydas*	—	—	26-12-1989	Florida, USA	
	SI NMNH 313719	*Chelonia mydas*	—	—	26-12-1989	Florida, USA	
	SI NMNH 313743	*Chelonia mydas*	—	—	06-11-1988	Virginia, USA	
Waseda University, Tokyo	RH 800	*Chelonia mydas*	Almost complete	—	—	—	R. H.
	RH 229	*Caretta caretta*	Complete	—	—	—	
	RH 786	*Caretta caretta*	Complete	—	—	—	

*: The inventory numbers of these two specimens were not available at time of examination due to a recent water damage in the collection.

Unfortunately, no sex data of the specimens studied were available (except for specimen RBINS 13.910, which was possibly female). Therefore, this aspect could not be included in this study. The skeletons did not show any obvious signs of pathologies or abnormalities that would have changed their skeletal morphology significantly.

Finding complete or nearly complete marine turtle skeletons with accurate species identifications proved to be challenging. Online search into collections databases demonstrates that most specimens of marine turtles consist only of the shell, or the shell and the skull, if such detail on present body parts is available. Moreover, a lot of specimens are kept mounted. Observing subtle osteomorphological

FIGURE 1 A sample of the fragmented and taphonomically modified green turtle (*Chelonia mydas*) humeri from Kinet Höyük viewed from the dorsal aspect [Colour figure can be viewed at wileyonlinelibrary.com]



Criterion	*Chelonia mydas*	*Caretta caretta*
1	When viewed from the dorsal aspect, a ridge is extending halfway the facies dorsalis. The cross-section near the extremitas omalis coracoidei is triangular.	When viewed from the dorsal aspect, no ridge is present on the facies dorsalis. The cross-section near the extremitas omalis coracoidei is round.

FIGURE 2 Diagnostic criteria for the (right) coracoideum viewed from the dorsal aspect

features in mounted skeletons is not convenient as the mounted state hampers viewing. We sought unmounted skeletons to be able to hold the skeletal elements in our hands and turn them around freely and to compare them with the skeletal elements from other recent, archaeological and palaeontological specimens. Nevertheless, we also worked with mounted skeletons when we had no better choice. Another challenge was that many of the collections we visited included only one of the species we were interested in, but not all different Mediterranean species for comparison.

4 | DESCRIPTION OF DIAGNOSTIC OSTEOMETRIC AND OSTEOMORPHOLOGICAL CRITERIA

4.1 | Coracoideum

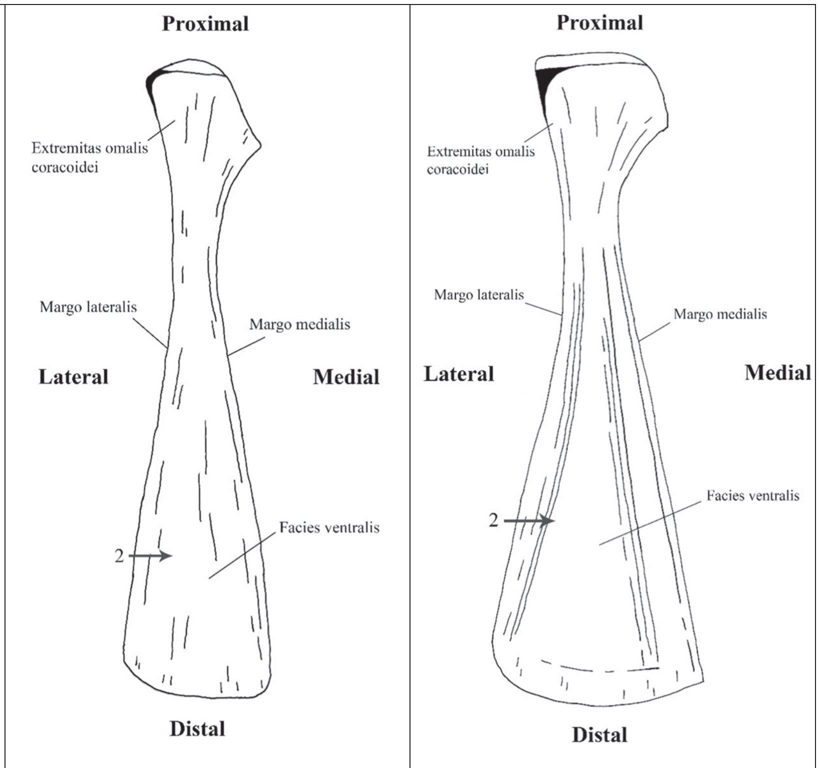
The coracoideum has two features that allow distinction between *Chelonia mydas* and *Caretta caretta*. When the coracoideum is viewed from the dorsal side, a slight ridge extends halfway along the facies dorsalis in *Chelonia mydas* (Figure 2, Criterion 1). However, this feature was variably pronounced among the *Chelonia mydas* specimens we observed; it was not easy to see in all the specimens. In *Caretta caretta*, this dorsal ridge is lacking. The second criterion is visible when the coracoideum is viewed from the ventral side: In *Chelonia mydas*, the distal part of the facies ventralis is flat, whereas in *Caretta caretta* the distal part of the Facies ventralis is concave, forming a slight depression or scoop (Figure 3, Criterion 2).

The two Coracoidea of *Eretmochelys imbricata* and *Dermochelys coriacea* we could investigate both showed a very sharp ridge on the facies dorsalis (much sharper than in *Chelonia mydas*) that extended further distally than in *Chelonia mydas*. The facies ventralis is flat in both species.

4.2 | Humerus

The GL/BSH index (Figure 4) demonstrates that the overall shape of the humerus is different in the two species. The humerus is slender in *Caretta caretta* and broader in *Chelonia mydas*. This difference in slenderness is displayed in individuals with small body sizes as well as in large-bodied individuals.

At the proximal end, the outline of the facies articularis of the caput humeri is slightly pointed in *Chelonia mydas*, whereas it is more rounded in *Caretta caretta* when observed from the dorsal aspect (Figure 5, Criterion 1). However, this feature is not always easily recognizable in all specimens. The tuberositas deltoidea is another important feature that differentiates



Criterion	*Chelonia mydas*	*Caretta caretta*
2	When viewed from the ventral aspect, the distal part of the facies ventralis is flat.	When viewed from the ventral aspect, the distal part of the facies ventralis is concave.

FIGURE 3 Diagnostic criteria for the (right) coracoideum viewed from the ventral aspect

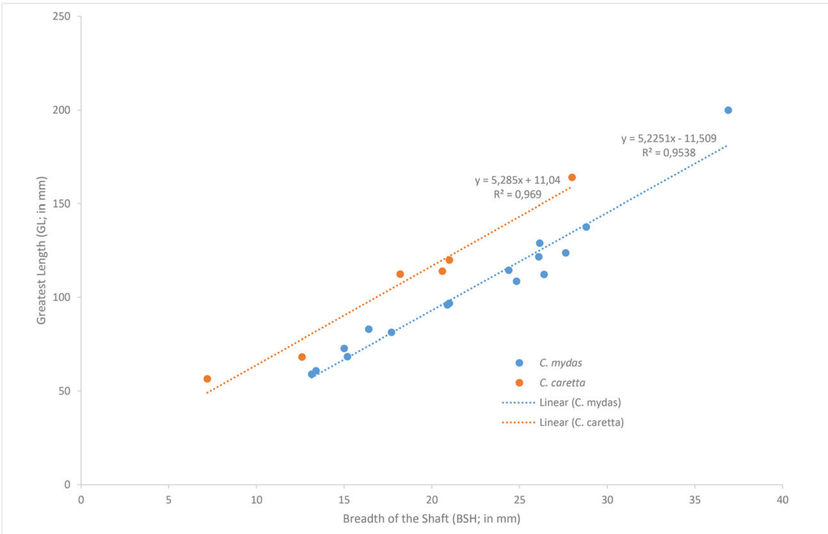


FIGURE 4 Index of the greatest length (GL) and the breadth of the shaft (BSH) of the humerus of *Chelonia mydas* and *Caretta caretta* [Colour figure can be viewed at wileyonlinelibrary.com]

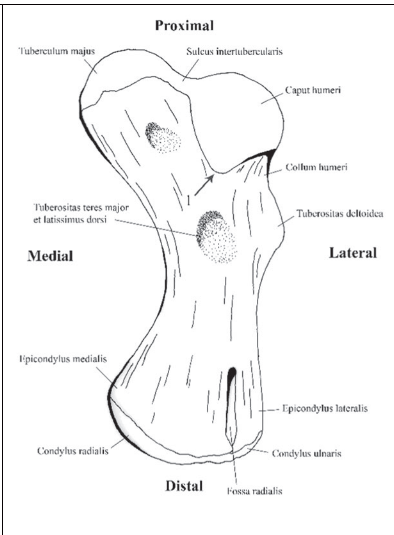
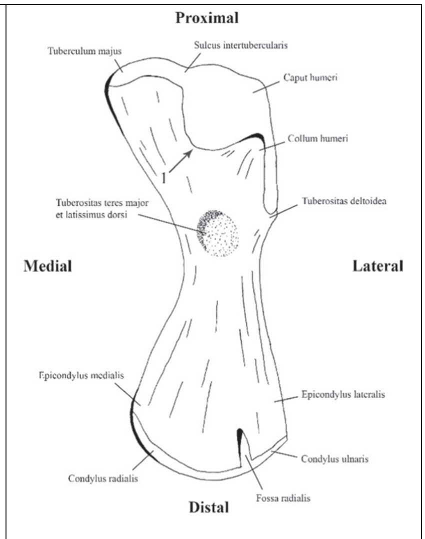
		
Criterion	*Chelonia mydas*	*Caretta caretta*
1	When viewed from the dorsal aspect, the outline of the facies articularis of the caput humeri is slightly pointed.	When viewed from the dorsal aspect, the outline of the facies articularis of the caput humeri is rounded.

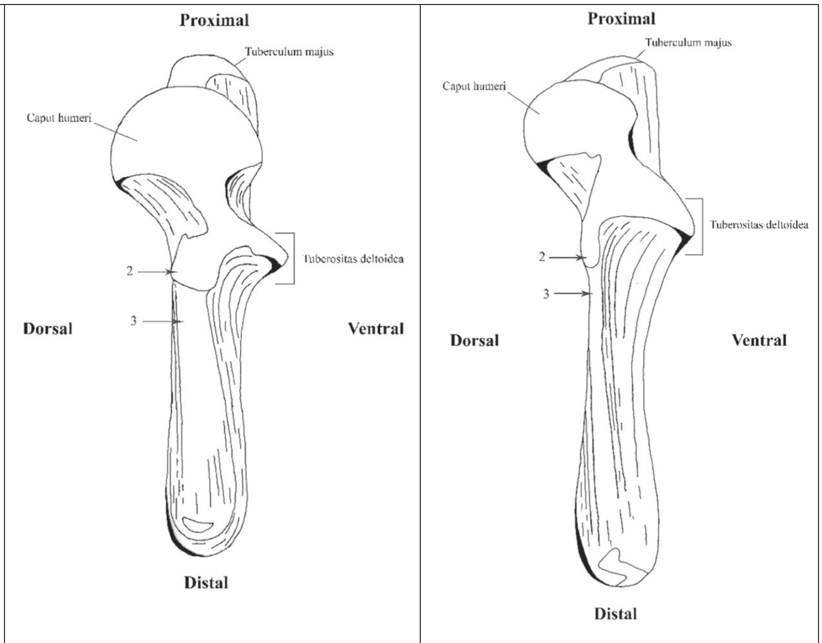
FIGURE 5 Diagnostic criteria for the (right) humerus viewed from the dorsal aspect

Chelonia mydas from *Caretta caretta*. When the humerus is observed from the lateral view, the shape of the distal edge of the tuberositas deltoidea is broad and rectangular in *Chelonia mydas*, and rather narrow and pointed in *Caretta caretta* (Figure 6, Criterion 2). The shaft also shows clear differences between the two species. The margin below the tuberositas deltoidea, when observed from the lateral view, is round and broad in *Chelonia mydas*, whereas it forms a sharp ridge in *Caretta caretta* (Figure 6, Criterion 3). In addition, the general appearance from the lateral aspect of the humerus is broad and round in *Chelonia mydas* and narrow and sharp in *Caretta caretta*. Criteria 2 and 3 were consistently distinguishing the species in all the specimens we observed.

In the one specimen of *Eretmochelys imbricata* we had the opportunity to observe, the facies articularis of the caput humeri was rounded as in *Caretta caretta*, whereas the morphology of the tuberositas deltoidea was neither broad, nor narrow, but oval. The morphology of the humerus of *Dermochelys coriacea* deviates extremely from the other three species as has already been described by Hay (1908, pp. 15–16), Hirayama (1992, p. 18), and Völker (1913, pp. 453-455).

4.3 | Femur

We observed only one distinguishing nonmetric feature on the femur between *Chelonia mydas* and *Caretta caretta*. In *Chelonia mydas*, when viewed from the posterior aspect, the proximal and distal



Criterion	*Chelonia mydas*	*Caretta caretta*
2	When viewed from the lateral aspect, the shape of the distal edge of the tuberositas deltoidea is broad and rectangular.	When viewed from the lateral aspect, the shape of the distal edge of the tuberositas deltoidea is narrow and pointed.
3	When viewed from the lateral aspect, the margin below the tuberositas deltoidea is round and broad.	When viewed from the lateral aspect, the margin below the tuberositas deltoidea forms a sharp ridge.

FIGURE 6 Diagnostic criteria for the (right) humerus viewed from the lateral aspect

epiphyses are broad compared with the diaphysis, forming a pronounced hourglass shape, whereas in *Caretta caretta*, the proximal and distal epiphyses are less broad compared with the diaphysis, creating a less pronounced hourglass shape (Figure 7, Criterion 1). In the one *Eretmochelys imbricata*, we were able to observe this aspect was similar to *Chelonia mydas*.

The GL/BSH index demonstrates this difference in the femora of *Chelonia mydas* and *Caretta caretta* osteometrically (Figure 8). As in the humeri of the two species, the femur of *Caretta caretta* is more slender than *Chelonia mydas*. Interestingly, the difference between the GL and the BSH of the femur between *Chelonia mydas* and *Caretta caretta* also seems to increase as individuals get older, suggesting that osteometrical differences between both species become more evident in mature individuals. Nevertheless, both scatter plots indicate that differences are already present in smaller (juvenile) individuals.

4.4 | Scapula/radius/ulna/tibia/fibula

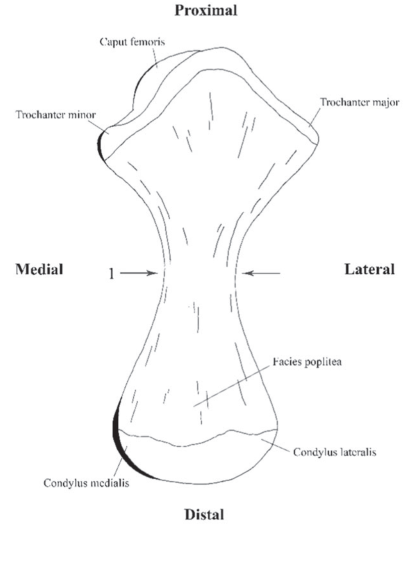
In addition to coracoideum, humerus and femur, we also examined scapula, radius, ulna, tibia and fibula. These elements did not show any obvious features allowing the distinction between *Chelonia mydas* and *Caretta caretta* for now. However, these elements have not been examined in the same detail as coracoideum, humerus, and femur, and a more systematic examination and evaluation of them should be conducted in order to verify this initial observation.

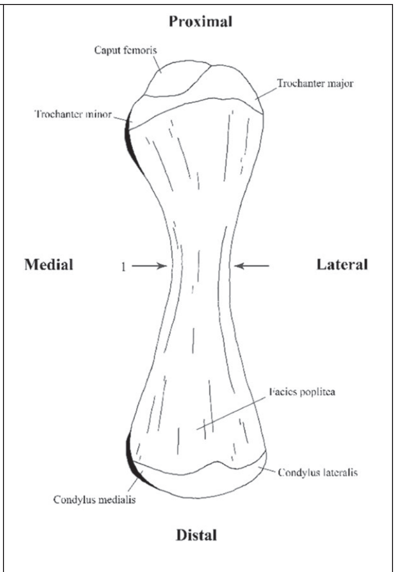
5 | APPLICABILITY OF THE CRITERIA

Of the published criteria, only one pertains to differences in limb bones of *Chelonia mydas* and *Caretta caretta*. According to Parham and Fastovsky (1997, pp. 550–551, table 1, Criterion 1), the angle between the processus dorsalis of the scapula and the acromion is wider than 110° in *Chelonia mydas*, *Eretmochelys imbricata*, and *Natator depressus*, whereas it is roughly 90° in *Caretta caretta* and *Lepidochelys* (it is not specified whether this concerns *Lepidochelys olivacea* or *Lepidochelys kempi* or both). However, in archaeological assemblages, the scapula is rarely preserved in a state allowing to measure this angle.

As seen in Figures 4 and 8, the difference in the overall shape of the humeri and femora of *Chelonia mydas* and *Caretta caretta* can be distinguished by osteometrics. However, due to the high-level fragmentation caused primarily by bio-agents (probably dogs), none of the humeri and femora in our zooarchaeological assemblages could be identified using this osteometric method.

Some criteria are more consistent than others. Table 3 summarizes the accuracy of the criteria for each element according to our observations (n = 16). The criteria marked as “good” were consistent and clearly visible at all the examined specimens. The criteria marked as





Criterion	*Chelonia mydas*	*Caretta caretta*
1	When viewed from the posterior aspect, the proximal and distal epiphyses are broad compared to the diaphysis, forming a pronounced hourglass shape.	When viewed from the posterior aspect, the femur is more slender than in *Chelonia mydas*, the proximal and distal epiphyses are less broad compared to the diaphysis, forming a less pronounced hourglass shape.

FIGURE 7 Diagnostic criteria for the (right) femur viewed from the posterior aspect

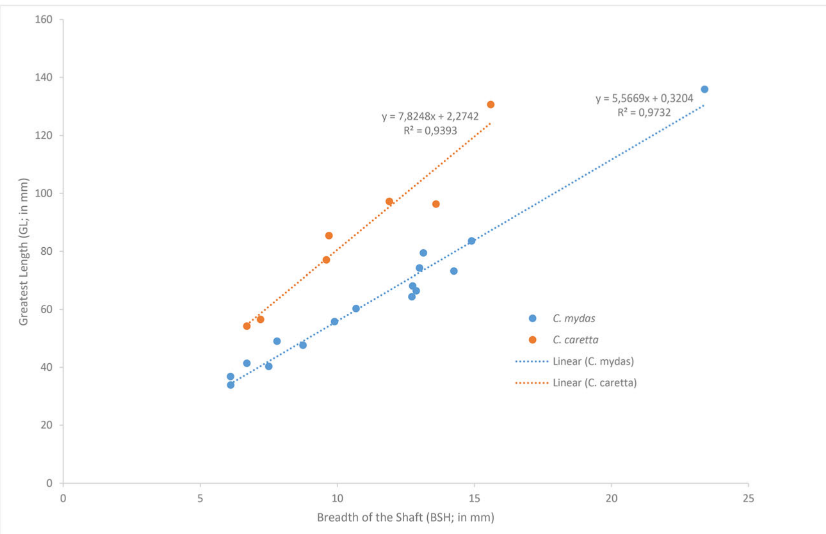


FIGURE 8 Index of the greatest length (GL) and the breadth of the shaft (BSH) of the femur of *Chelonia mydas* and *Caretta caretta* [Colour figure can be viewed at wileyonlinelibrary.com]

"medium" were not always consistent or sometimes not visible during our observations; however, they are still useful as an additional criterion. The two criteria for the coracoideum were not always consistent or clearly defined on all specimens and therefore marked as "medium." On the humerus, the criterion for the outline of the facies articularis (Criterion 1) of the caput humeri was not always evident or consistent in all examined specimens. The criterion for the tuberositas deltoidea (Criterion 2) and the diaphysis (Criterion 3), however, showed clear differences, which were consistent in all examined specimens. In addition, both criteria were also visible on the bulk of the archaeological marine turtle remains, making these useful criteria, especially for fragmented or eroded material. The criterion on the femur is also an evident feature allowing consistent distinction between species. However, this criterion was difficult to employ on the archaeological material due to the bad preservation or the absence of the proximal and distal epiphyses.

TABLE 3 Summary of the accuracy of the criteria for each element discussed in this paper based on our observations (n = 16)

Criterion	Accuracy
Coracoideum	
Corpus coracoidei (Figure 2, Criterion 1)	Medium
Corpus coracoidei (Figure 3, Criterion 2)	Medium
Humerus	
Caput humeri (Figure 5, Criterion 1)	Medium
Tuberositas deltoidea (Figure 6, Criterion 2)	Good
Diaphysis (Figure 6, Criterion 3)	Good
Femur	
Diaphysis (Figure 7, Criterion 1)	Good

TABLE 4 Overview of the identified Cheloniidae limb bones from Kinet Höyük and Tell Fadous-Kfarabida and the used criterion/criteria from the present study

Site				
Element	Taxon	Kinet Höyük	Tell Fadous-Kfarabida	Used criteria/criterion
Humerus	Green turtle (*Chelonia mydas*)	31	—	Criteria 2 and 3
	Loggerhead (*Caretta caretta*)	1	4	Criteria 2 and 3
Femur	Green turtle (*Chelonia mydas*)	1	—	Criterion 1
	Loggerhead (*Caretta caretta*)	—	4	Criterion 1
Total		33	8	

A total of 33 marine turtle limb bones (32 humeri and one femur) from Kinet Höyük were examined using the criteria presented in this study. Based on criteria 2 and 3 on the humerus, we identified 31 humeri as *Chelonia mydas* and one humerus as *Caretta caretta* (Table 4). The femur was identified as *Chelonia mydas*. At Tell Fadous-Kfarabida, we looked at eight limb bones (four humeri and four femora) from marine turtles. All eight specimens were identified as *Caretta caretta* based on Criteria 2 and 3 on the humerus and the single criterion on the femur.

6 | CONCLUSIONS

Distinguishing between marine turtle species based on their skeletal remains is crucial to determine the differential significance of each species to the people who interacted with them in the past. It is also necessary for conservation biologists who deal with recent specimens, for example, on beaches and in forensic cases at customs. This study aimed at developing a user-friendly and accurate guide to distinguish the closely related *Chelonia mydas* and *Caretta caretta* coracoideum, humerus, and femur remains from archaeological sites and natural deposits based on comparative osteomorphological observations on recent specimens. Our observations show that although some criteria are more consistent than others, the two species can be distinguished based on osteomorphological criteria. Especially in the humerus (Criteria 2 and 3) and the femur (Criterion 1), the criteria we define are consistent and easy to detect. Features on the proximal humerus (Criterion 1) and the coracoideum (Criteria 1 and 2), on the other hand, were sometimes more subtle on the specimens we observed. The described criteria also perform well when dealing with fragmented and eroded archaeological material. Metrics provide accurate identifications if humeri and femora are preserved in full height.

Future research should involve analysts with different levels of experience, (blind-)testing these criteria using a broader range of specimens, and if possible, develop additional criteria, taking variability across age, sex, and regional populations in consideration. Adding more species to the comparative study within the Cheloniidae family will allow applications in regions where more Cheloniidae species occur on a regular basis today and in archaeological deposits.

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